TRACKING GENERATOR FOR
A MICROWAVE SPECTRUM ANALYZER

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ABSTRACT

A tracking generator for the spectrum analyzer HP8569A is designed. It consists of a mixer and an oscillator, an amplifier and a frequency multiplier for an output frequency range from 5.8 GHz to 12.9 GHz. Circuits are optimzed by simulation and measurements. The resulting instrument provides a test signal with high spectral purity.

1 INTRODUCTION

Scalar network analysis is often used to determine the behaviour of RF devices or modules. A network analyzer measures the transmission and reflection characteristics of active and passive devices, e. g. the frequency response or insertion loss of a filter. It consists of a sweepable frequency source and a detector. The spectrum analyzer, however, has only a receiving unit. For measurements on non-transmitting devices an additional signal generator is needed. This generator has to "track" the spectrum analyzer's frequency, i. e. it has to transmit on its receiving frequency. Such a generator is called "tracking generator".

A spectrum analyzer is permanently sweeping the monitored frequency range through variation of the internal LO (local oscillator) frequency. To guarantee that the tracking generator always produces the correct signal frequency, the LO frequency of the spectrum analyzer is used as input signal for the tracking generator. It is available at the "LO out" port of the spectrum analyzer.

The Hewlett Packard Spectrum Analyzer HP8569A covers a frequency range from 10 MHz to 22 GHz which is divided into six bands. The tracking generator was developed for the third band from 5.8 GHz to 12.9 GHz. The HP8569A has a first LO frequency between 2.05 GHz and 4.46 GHz and a first IF (intermediate frequency) of 321.4 MHz. The various bands are generated by LO frequency multiplication and subsequent downconversion. For example, a LO frequency of 3.0 GHz multiplied by 3 results in 9.0 GHz. Mixing to the IF results in a receiving frequency of 8.7 GHz (9.0GHz – 0.3GHz = 8.7GHz). Since only the first LO frequency is available at an extra output port, the tracking generator has to do the band conversion itself.

2 CONCEPT

The required modules for the tracking generator mainly depend on the spectrum analyzer's frequency concept. In the band of interest, the analyzer uses the third LO harmonic:

$$f_{RX} = 3 \cdot f_{LO} - f_{IF,spec} . \quad (1)$$

The transmit frequency f_{TX}, which is produced by the tracking generator, must be equal to f_{RX}. To achieve the correct transmit frequency, $f_{IF,spec}$ has to be subtracted from the triple LO frequency. But as it is much easier to realize a mixer at lower frequencies, the formula can be transposed to the following:

$$f_{TX} = f_{RX} = 3 \cdot (f_{LO} - \frac{1}{3} f_{IF,spec}) = 3 \cdot (f_{LO} - f_{IF,track}) . \quad (2)$$

Equation (2) looks very similar to equation (1), but it has a different meaning for construction. At first, a third of the spectrum analyzer's IF is subtracted from the LO frequency. So the frequency mixer circuit has to work at a maximum frequency of about 4.5 GHz and not up to 13 GHz.

Finally, the resulting frequency is multiplied by three. This concept needs two filters before and after the frequency multiplier stage. Additional amplifiers lead to the block diagram in Fig. 1.

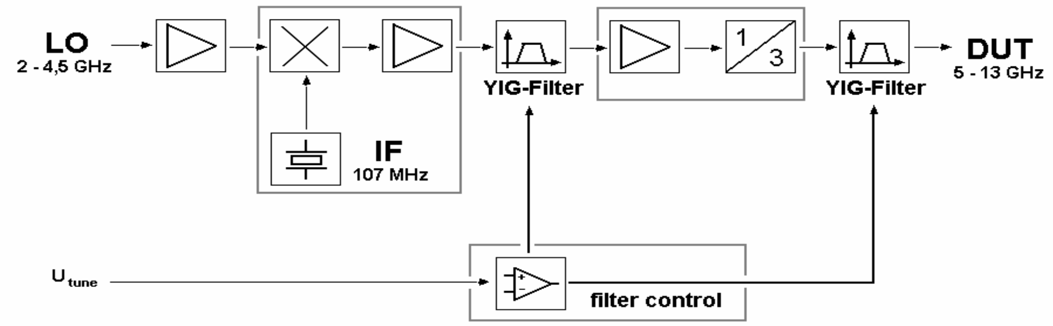

Fig. 1: *Block diagram of the tracking generator*

The input signal is the LO frequency of the spectrum analyzer. The first amplifier serves as an isolation amplifier which avoids feedback from the tracking generator to the spectrum analyzer. A reverse attenuation of 60 dB was realized. In addition to that, the LO signal level is increased to +7 dBm for the following mixer.

Mixer, IF oscillator and another buffer amplifier are combined in the second module. The IF of the tracking generator is 107.13 MHz, which is one third of the spectrum analyzer's IF. This module does not contain frequency selection.

The desired frequency $f_{LO} - f_{IF,track}$ is selected by the first YIG (yttrium iron garnet) filter [1]. It is possible to vary the resonance frequency of the YIG filter with a tuning voltage. This tuning voltage is generated by an analog control circuit which uses the tuning voltage of the spectrum analyzer as control signal. An integrated YIG filter driver transforms the tuning voltage into a tuning current.

The third module contains a two-stage amplifier and a frequency tripler. It is followed by the second YIG filter, which selects the third harmonic in the frequency range between 5.8 GHz and 12.9 GHz. There is no further amplifier needed behind the frequency multiplier.

3 MODULES

3.1 OSCILLATOR AND MIXER MODULE

A fifth-overtone crystal oscillator generates the IF signal at 107.13 MHz. The oscillator uses a colpitts circuit with a JFET [2]. Two capacitors and one inductor build up a resonant circuit for 107 MHz. The crystal must only stabilize the given resonant frequency. To avoid parasitic resonances at lower frequencies, an additional inductor is used for neutralization of the static capacitance C_0 of the crystal [1]. The mixer is a Mini Ciruits MCA-1-42, followed by a MMIC Gali-1. The PCB of the module is designed for 1.5mm thick FR4 material.

3.2 TWO-STAGE AMPLIFIER

The first step of the amplifier development was a simulation with APLAC [3]. Two MMICs of the same type (Gali-1) are used. In general, it is very useful to do simulations before building circuits or modules. APLAC is a powerful RF circuit simulation program. It is possible to include active and passive devices as well as microstrip lines, and to optimize circuits by manual tuning or with various algorithms. In the simulation, the amplifiers are represented through their S-parameters which are available from the manufacturer. Only those elements are included in the simulation circuit which are relevant to the RF tranfer function.

Fig. 2 shows the simplified schematic diagram. The element values of the filter circuit were optimized for constant gain in the frequency range between 2.0 GHz and 4.5 GHz. The inductivities *'L_through'* represent the ground vias for the MMICs.

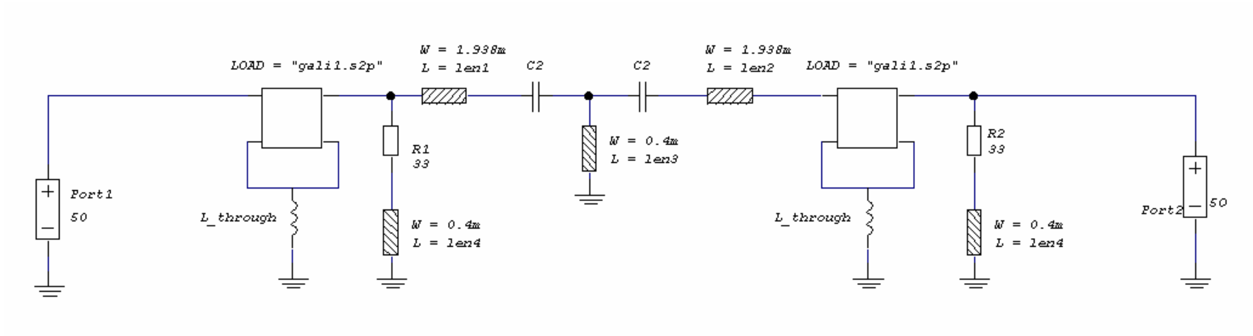

Fig. 2: *APLAC simulation circuit of two-stage amplifier*

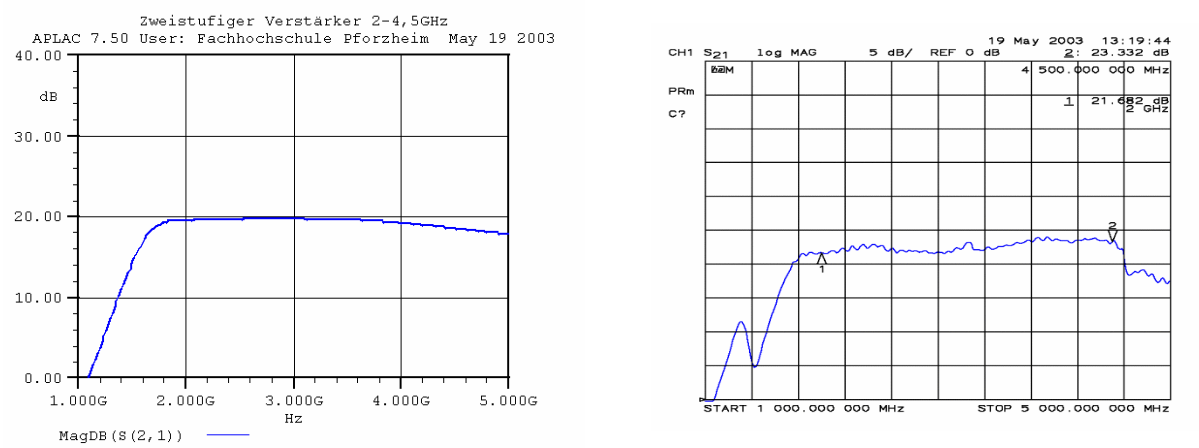

Fig. 3: *Simulation (left) and measurement (right) of* S_{21}

Results of simulation and measurement of S_{21} are shown in Fig. 3. In the simulation a gain of 20 dB is reached while the real circuit amplifies almost 23 dB.

3.3 FREQUENCY MULTIPLIER CIRCUIT

Several different bipolar transistors and FETs were tested for the active element of the frequency tripler. This circuit was not simulated because reliable nonlinear models are not available for all tested semiconductors.

While it is clear that a bipolar transistor produces all higher order harmonics because of its exponential characteristic, a FET which has a quadratic transfer function is usually thought to provide only second order harmonic distortion.

The output current I_D of a FET over its input voltage U_{GS} can be described as

$$I_D = \frac{K}{2} \cdot (U_{GS} - U_{th})^2 \qquad \text{for } U_{GS} \geq U_{th} \qquad (3)$$

$$I_D = 0 \qquad \text{for } U_{GS} \leq U_{th}$$

where K is a constant and U_{th} is the threshold voltage. [4]

Under small signal conditions the transfer function can be linearized and the transistor produces no harmonics. With large signals a dominant second harmonic is generated as long as the input voltage remains larger than U_{th} during the whole period.

If in contrast the bias is adjusted such that the conduction angle is less than 360°, the function is no longer purely parabolic and higher order harmonics are generated. Fig. 4 illustrates this behaviour; the threshold voltage of the device under test was about -1.2 V. With a bias of less than –0.3 V clipping starts to produce a third harmonic signal while at the same time the fundamental amplitude decreases. The second harmonic remains quite independent from the bias point.

With proper bias adjustment a frequency tripler can be realized. It is even possible to use self-biasing from the gate current generated through RF rectification if the input power can be kept at a constant level.

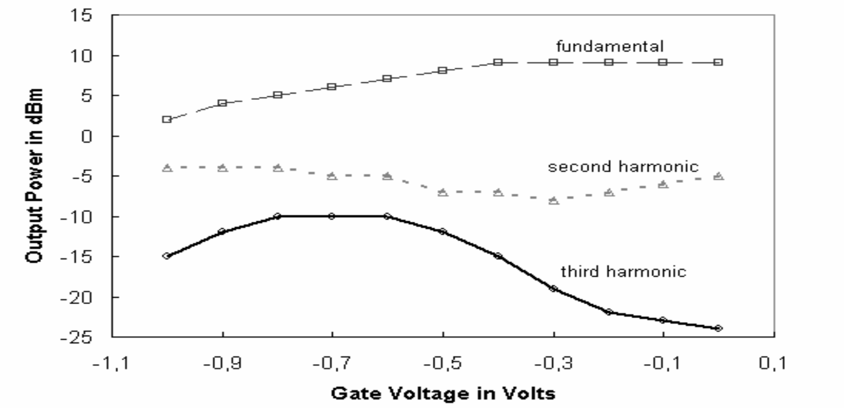

Fig. 4: *Power of harmonics over gate bias voltage U_G (MGF1302, +7dBm in)*

All transistor tests were done on two extra developed PCBs (material RO4003) and at an input power of 10 dBm. The two PCBs are for the two different package layouts. Aim of the testing was to find a transistor with high and linear output power of the third harmonic in the frequency range between 5.8 GHz and 12.9 GHz.

Tested transistor types:

Type	Description	Package	Manufacturer
BFP420	NPN Silicon RF transistor	SOT343 (plastic)	Infineon Technologies
BFP620	NPN SiGe[1] RF transistor	SOT343 (plastic)	Infineon Technologies
ATF34143	PHEMT[2] 800 µm gate width	SOT343 (plastic)	Hewlett-Packard
ATF10736	GaAs[3] FET 500 µm gate width	36 micro-X (ceramic)	Hewlett-Packard
MGF1302	GaAs FET 250µm gate width	GD-4 70 mil (ceramic)	Mitsubishi Semiconductor

[1]) SiGe = Silicon Germanium
[2]) PHEMT = Pseudomorphic High Electron Mobility Transistor
[3]) GaAs = Gallium Arsenide

The bipolar transistors BFP420 and BFP620 are not really satisfactory. In the range below 10 GHz, they have high gain and the third harmonic's level is quite frequency independent with small variations. Above 10 GHz the gain decreases rapidly and the output power is varying more. The ATF34143 has similar results to the BFP types. Its conversion loss varies less between 10 GHz and 12 GHz, but the output power is lower. The ATF10736 can achieve good results in respect to output power, but the input power has to be increased to 13 dBm.

In the end, the MGF1302 was decided to be the best suited transistor. It has acceptable output power over the whole desired frequency range with a conversion loss of about 17 dB. Around 11 GHz the third harmonic's level was even a bit higher than at 9 GHz or 10 GHz. Since the three SOT343 packaged transistors had similar results, an influence of the package parasitics is supposed. The MGF1302 is housed in a microwave metal-ceramic package. [5]

The modul which contains the two-stage amplifier and the frequency tripler is developed for a 31 mil RO4003 substrate, because FR4 material has too high losses on frequencies above 10 GHz.

4 CONCLUSION

The desired performance and simulated requirements of the tracking generator have been realized. An output frequency range from 5.8 GHz to 12.9 GHz is covered with a minimum output power of -10 dBm which extends the HP8569A for scalar network analysis with more than 60 dB dynamic range.

REFERENCES

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[3] APLAC 7.50 Users Guide Vol. 1.

[4] Tietze, U., Schenk, C., Halbleiterschaltungstechnik, 11. Auflage 1999. Springer-Verlag Berlin Heidelberg.

[5] Datasheets BFP420 and BFP620 from Infineon Technologies, ATF34143 and ATF10736 from Hewlett-Packard, MGF1302 from Mitsubishi Semiconductor.